Factors affecting sow colostrum yield and composition, and their impact on piglet growth and health

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Abstract

Investigations were conducted on sow physiology around farrowing, acute phase protein (APP) response and their association with colostrum yield (CY), colostrum composition and piglet colostrum intake (CI). The study included 229 sows with 3,210 live-born piglets from five Finnish and one Dutch sow herds. Sow farrowing was supervised, and piglets were individually weighed at birth (BWB) and 24 h after birth of first piglets in order to calculate piglets CI and sow CY. Colostrum nutritional composition, immunoglobulin (Ig), serum amyloid A (SAA) and haptoglobin (Hp) contents were assessed. Sow plasma SAA, Hp and progesterone around farrowing were also assessed. Selected ear-tagged piglets were weighed at 3 to 4 weeks of age to calculate individual average daily gain. Sow CY was positively correlated with plasma Hp ($P = 0.029$) and number of live-born piglets ($P < 0.01$). An additional minute of farrowing duration lower the CY by 2.2 g ($P = 0.01$). Piglet CI was positively associated with piglet weight at birth ($P < 0.001$) and negatively associated with the number of live-born piglets in the litter and percentage of protein in the colostrum ($P < 0.001$). Both piglet CI and birth weight were positively associated with piglet average daily gain (ADG) ($P < 0.001$). Piglet survival from birth to weaning depends on CI.

Keywords	Farrowing; Environment; Acutephaseproteins; Piglet mortality; Antibiotic
Taxonomy	Biochemistry, Agriculture

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No data was used for the research described in the article

Dear Editor,

First of all, we are glad to submit our research article to Animal Reproduction Science .

This study investigated different sow's and piglets' related factors affecting sow colostrum yield (CY), colostrum quality and subsequent litter performance. We think this work can give a good input in the evolving research in the pig reproduction, management and welfare.

We have no previous interactions about this manuscript with an Academic Editor of this Journal, and no specific opposed reviewers.

Being aware of their outstanding work done in this specific field, we would like to suggest Nicolas Devillers (nicolas.devillers@agr.gc.ca) and Hélène Quesnel (helene.quesnel@rennes.inra.fr) as possible reviewer of this manuscript.

On behalf of all co-authors,

Shah Hasan

Highlights

1. A prolonged duration of farrowing and low Hp in sow plasma decreased sow CY.
2. Insufficient CI could lead to a significant increase in piglet mortality until weaning.
3. Weaning weights of the piglets were found to be dependent on CI.
4. High body reserves are important at the start of lactation for the piglet growth and survivability.

Factors affecting sow colostrum yield and composition, and their impact on piglet growth and health

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Abstract

Investigations were conducted on sow physiology around farrowing, acute phase protein (APP) response and their association with colostrum yield (CY), colostrum composition and piglet colostrum intake (CI). The study included 229 sows with 3,210 live-born piglets from five Finnish and one Dutch sow herds. Sow farrowing was supervised, and piglets were individually weighed at birth (BW_B) and 24 h after birth of first piglets in order to calculate piglets CI and sow CY. Colostrum nutritional composition, immunoglobulin (Ig), serum amyloid A (SAA) and haptoglobin (Hp) contents were assessed. Sow plasma SAA, Hp and progesterone around farrowing were also assessed. Selected ear-tagged piglets were weighed at 3 to 4 weeks of age to calculate individual average daily gain. Sow CY was positively correlated with plasma Hp ($P = 0.029$) and number of live-born piglets ($P < 0.01$). An additional minute of farrowing duration lower the CY by 2.2 g ($P = 0.01$). Piglet CI was positively associated with piglet weight at birth ($P < 0.001$) and negatively associated with the number of live-born piglets in the litter and percentage of protein in the colostrum ($P < 0.001$). Both piglet CI and birth weight were positively associated with piglet

average daily gain (ADG) ($P < 0.001$). Piglet survival from birth to weaning depends on CI. We found that the risk for piglets death or a piglet being treated with antibiotic before weaning increase with a decrease in sow back fat thickness at farrowing ($P = 0.04$). Similarly, we found that piglets of litters with low BW_B and low CI had higher risk of death before weaning ($P < 0.001$). Piglets born from sows having lower levels of colostrum IgA and SAA and high plasma progesterone at the end of farrowing had higher risk of neonatal diarrhea ($P = 0.04$; $P = 0.05$; $P = 0.04$). Piglets born from sows having higher back fat thickness at weaning had higher risk of developing weaning diarrhea ($P = 0.02$). Sow body condition and physiological status around farrowing affect CY and colostrum Ig. Piglet survival and risk of death before weaning also depend on CI. Therefore, to support CY and CI, measures should be taken to ease the process of farrowing, increase piglet vitality and improve colostrum availability for piglets.

Keywords

Farrowing; Environment; Acute phase proteins; Piglet mortality; Antibiotic

1. Introduction

Pre-weaning piglet mortality ranges from 10-13% in the principal pig-breeding countries (Ewdards, 2002; Kilbride et al. 2012) and it is well documented that insufficient colostrum intake (CI) is one of the major causes of mortality (Hales et al. 2014; Decaluwé et al. 2014) . Studies reported that approximately 30% of hyper prolific sows produce insufficient colostrum for their litters Foisnet et al. 2010; Decaluwé et al. 2013), despite colostrum being the only source of energy and passive immunity for the neonate (Rooke and Bland 2002; Le Dividich et al. 2005). Hyper prolific sows apparently also have a longer farrowing duration (Björkman et al. 2017) which could impair colostrum production. Most pre-weaning mortality occurs during the first 3 days after birth (Le Dividich et al. 2005; Shankar et al. 2009; Muns et al. 2016) . Inadequate CI by the piglet is a leading cause of mortality during the first days after birth due to hypoglycemia, and consequently

hypothermia (Le Dividich et al. 2005). In addition, insufficient intake of maternally-derived immunoglobulins (Ig) has a negative effect on piglet health status, which has a carry-over effect on weight gain and survival (Decaluwé et al. 2014; Quesnel et al. 2012; Declerck et al. 2016).

Assessment of this issue at the farm level, can be complicated because sow colostrum yield (CY) and colostrum Ig content and composition may vary considerably among sows (Devillers et al. 2007; Declerck et al. 2015; Hasan et al. 2016). This variation can be attributed to sow, piglet and environmental features (Quesnel, 2011; Declerck et al. 2015; Declerck et al. 2017). Associations between changes in the energy reserves and CY in late gestating sows were reported by Decaluwé et al. (2013): they found that sow CY was negatively associated with late gestation loss of back fat and consequently with sows arriving at farrowing with a reduced body condition. Some studies have also shown that CY is independent of litter size, thus, a higher number of live-born piglets per litter resulted in a lower CI per piglet (Devillers et al. 2007; Declerck et al. 2015). We conducted our study in commercial piggeries. We measured some physiological parameters of the sows, CY, colostrum composition, piglet CI and their association with piglets growth and mortality until weaning. Because physiology of farrowing and colostrum production are strictly connected (Algers and Uvnäs-Moberg, 2007), it is feasible any health impairment or disturbance of the homeostasis right before and during the farrowing process can be detrimental to CY. A certain degree of inflammation and tissue damage at farrowing are inevitable (Mainau and Manteca, 2011), but if farrowing is too prolonged and complicated (dystocia, hormonal impairment, stress due to housing constriction) it can develop into a severe pathological state (Mainau and Manteca, 2011). Disturbances in homeostasis due to inflammation, tissue injury during gestation and the farrowing process can induce a nonspecific acute phase response (Sorrells et al. 2007). We hypothesize that measuring some pig acute phase proteins (APPs) would provide additional information on abnormal inflammatory or tissue damage effects at farrowing on CY, Ig content and colostrum composition. Another hypothesis was that large litters might have adverse effect on sows, such as longer

74 farrowing duration, possibly altering sow physiology and increasing the risk for hormonal
75 disruptions and inflammation. We also hypothesized that a large litter size and longer farrowing
76 duration would be negatively associated with CY, CI, Ig content, colostrum composition, piglet
77 survival and piglet growth until weaning.

78 2. Materials and methods

79 The experimental protocol was approved by the National Animal Experiment Board in
80 Finland (ESAVI, Regional State Administrative Agency for Southern Finland, permission
81 ESAVI/333/04.10.03/2011) and by the Dutch authority CCD (The study performed in the
82 Netherlands did not require a special license under the Dutch Animal Procedures Act, decision
83 26.04.2017).

84 *2.1 Study population and experimental design*

85 The study was carried out in hers on six commercial pig farms, described as herds 1- 6 later
86 in Tables 1 and 2 (five in Finland and one in the Netherlands). Four different sow breeding lines
87 were represented in these farrow-to-finish herds: DanAvl (n = 2), Topigs TN70 (n = 2), Duroc ×
88 Norwegian Landrace (n = 1) and Topigs 20 (n = 1). The main herd characteristics are shown in
89 Table 1, including sow breeds and the number of sows studied per herd. During pregnancy sows
90 were loose housed and feed was served in individual feeding cages. Approximately one week
91 before expected farrowing the sows were transferred to the farrowing room, where they were
92 housed individually either in farrowing crates (n = 5 herds) or a farrowing pen (n = 1 herd). In herd
93 6, sows were kept in getaway pens in a group farrowing system. Within a herd, sows were selected
94 on the basis of start of farrowing on a first come first sample principle. Sows farrowed
95 spontaneously and the researcher sampled all sows upon availability at farrowing. No restrictions on
96 parity of the sows were imposed, but it was taken into account in that it was uniformly distributed
97 across the different herds. Parturition was observed with minimal interference in the farrowing

process. The farrowing duration was calculated based on the birth of the first piglet representing the beginning, and the expulsion of the last piglet the end. When a piglet was born, its back was dried with a paper towel, in order to allow the birth rank number to be marked on the back with a thick marker, and the birth weight (BW_B) was taken. During the first 24h from the start of birth, piglets were allowed to consume only maternal colostrum. No additional feed supplement was allowed before they had been weighed for CI calculation (24 h after the start of farrowing. Six piglets from each litter were selected and ear-tagged based on BW_B in a block of three categories, 2 piglets weighed <1 kg, 2 piglets 1.4-1.8 kg and 2 piglets >1.8 kg, representing small, normal and large piglets, respectively. Cross-fostering was allowed only after the 24 h weighing, but not for the six selected piglets, which stayed with their original mother until weaning. Litters were balanced according to the number of functional teats, as it is usually done in commercial farms.

2.2 Measurements and definitions

All ear-tagged piglets were individually weighed at birth, 24 h after the start of farrowing and before weaning (3-4 weeks of age). The CY was calculated as the sum of the individual piglet CIs within a litter, as described by Devillers et al. (2004), using the following variables: BW_B (kg), weight at 17 to 24 h of age (BW_{24}, kg), duration of CI (t in min and 17 h $\leq$ t $\leq$ 24 h), and time between birth and first suckling (tFS, min). The regression equation was: $CI = -217.4 + 0.217 \times t + 1861019 \times BW_{24}/t + BW_B \times (54.80\text{-}1861019/t) \times (0.9985 - 3.7 \times 10\text{-}4 \times tFS + 6.1 \times 10\text{-}7 \times t2FS)$. The tFS was estimated to be 35 min, which was based on our observations from previous studies (Hasan et al. 2016) and was same as in a recent study (Decaluwé et al. 2013). An error of 15 min in tFS will generate a 6 g/kg BW_B miscalculation of CI for piglets or less than 2% error (Devillers et al. 2004). Sow back fat was measured at the level of the last rib, 6 to 7 cm from one side of the backbone using a digital back-fat indicator (Renco lean-meater®, Renco Corporation, Minneapolis, MN, USA) at farrowing (BF_F) and at weaning (BF_W). Observed sow parameters were: parity, gestation length, farrowing duration, back fat thickness at farrowing and weaning, and numbers of

123 live-born and stillborn piglets. Gestation length was calculated based on day of first insemination
124 (start) and day of parturition. Observed piglet parameters were: CI, birth interval (time interval
125 between births of individual piglets), pre-weaning mortality, BW_B, BW_{24}, body weight at weaning,
126 and average daily gain (ADG) from birth to weaning, use of antibiotics (during the first week of
127 age), diarrhea within 24 h of birth and diarrhea during the first week of life (from 24 h of birth to
128 one week of age).

129 ### *2.3 Samples*

130 Twenty milliliters of colostrum were collected from each sow within the first two hours after
131 birth of the first piglet. Colostrum samples were collected from the first three teats of same side of
132 the anterior udder. Samples were aliquoted and stored at -20°C until further analysis. Sow blood
133 samples were collected from the *vena saphena* at the beginning and at the end of farrowing using
134 lithium heparin tubes, and centrifuged at 1000 × g for 10 minutes, the plasma being separated,
135 aliquoted and stored at -20°C for further analysis. Blood samples were not collected from herd 6.

136 ### *2.4 Analyses of samples*

137 The standardized and complete methods for measuring colostrum composition were
138 described in (Hasan et al. 2016). Concentration of Ig was quantified using swine IgG, IgA and IgM
139 ELISA quantification Kits (Bethyl Laboratories, Montgomery, Texas, USA). The intra- and inter-
140 assay coefficients of variation were 4.8%, 3.3%, 1.3% and 6.7%, 5.3%, 6.8% for IgG, IgA and IgM
141 respectively. The colostrum total solid (TS), fat, protein and lactose contents were analyzed using
142 MilkoScanTM FT+ (Foss, Hillerød, Denmark), according to a validated method described in
143 previous study (Hasan et al. 2016). Colostrum and plasma serum amyloid A (SAA) were analyzed
144 with commercial multispecies indirect ELISA (PhaseTM SAA Assay, Tridelta Development Ltd.,
145 Kildare, Ireland) according to the manufacturer's instructions for swine. The intra- and inter-assay
146 coefficients of variation were 12% and 12% respectively. Colostrum and plasma haptoglobin (Hp)
147 concentrations were analyzed with a hemoglobin-binding assay developed for cows (Makimura and

148 Suzuki, 1982) with modifications, in which tetramethylbenzidine was used as a substrate and 5 µl as
149 a sample volume. Pooled and lyophilized aliquots of porcine acute phase serum were used as
150 standards. The assay was calibrated using a porcine serum sample of known Hp concentration
151 provided by the European Commission Concerted Action Project (number QLK5-CT-1999-0153).
152 The intra- and inter-assay coefficients of variation were 8% and 11% respectively. Blood plasma
153 progesterone was analyzed using radioimmunoassay (RIA) (Progesterone ImmuChem, ICN
154 Pharmaceuticals, USA).

155 *2.5 Data processing and statistical analysis*

156 A sow level dataset (outcome variables measured at sow level) was used to study sow level
157 variable associations between farrowing data and colostrum quality. Tree level hierarchical mixed
158 linear regression models were built to study variables associated with sow level continuous outcome
159 variables (farrowing duration, number of born piglets, CY, colostrum IgG, IgA and IgM
160 concentrations). Square root transformation (for colostrum IgA and IgM) and logarithmic
161 transformation (for colostrum IgG and farrowing duration) were used to achieve normal distribution
162 of outcome variables. Farm and trial batch within the farm were included as random factors in all
163 models.

164 For model building, univariate analyses with explanatory variables were performed.
165 Explanatory variables with $P \leq 0.2$ were included in the "full models". Full model for farrowing
166 duration included average piglets BW_B (g), back fat at farrowing (mm), number of born piglets as
167 continuous, and progesterone at farrowing (≤6 and >6 ng/ml) and parity category (1-2, 3-5 and >5)
168 as categorical explanatory variables. Full model for number of born piglets included gestation
169 length (days) and back fat at farrowing as continuous, and parity category as categorical
170 explanatory variables. The full model for CY included farrowing duration (min), plasma Hp (mg/l)
171 and number of born piglets as continuous, and parity category as categorical explanatory variables.
172 The full model for colostrum IgG included plasma SAA (mg/l) as continuous and feed and parity

category as categorical explanatory variables. The full model for IgA included farrowing duration and back fat at farrowing as continuous and parity category as categorical explanatory variables. The full model for IgM included plasma SAA, plasma Hp and farrowing duration as continuous, and parity category as categorical explanatory variables.

Stepwise backward elimination procedure was performed for final models. Linear relationship between outcome and continuous explanatory variables and squared explanatory variable was included (after centring to avoid collinearity) into the model when appropriate. Biologically meaningful interactions were checked. Possible confounding variables were tested (cofounding was defined as 15% change in variable coefficient). Collinearity between explanatory variables was explored using corresponding VIF values. Assumptions for all linear mixed models were confirmed using normality and scatter plots of model residuals.

Similar tree level mixed logit models were used to study associations among explanatory variables with dichotomous outcome variables (antibiotic treatment of sow or piglets – yes/no and litter diarrhea at 24 h post-partum – yes/no) in the sow level dataset. Farm and trial batch inside the farm were included as random factors. After univariate analysis final models were built similarly to the linear mixed models described above. The full model for antibiotic treatment of sow or piglets included number of live-born piglets, back fat at farrowing, back fat at weaning, plasma Hp, litter weight at 24 h (g) and colostrum Ig (mg/ml) as continuous, and parity category as categorical explanatory variables. The full model for litter diarrhea at 24 h post-partum included average piglet BW_B and colostrum SAA as continuous, and progesterone at the beginning of farrowing ($\leq$6 and >6 ng/ml) as categorical explanatory variables. The level of progesterone was considered higher when 6.0 ng/ml and > 4.9 ng/ml, at the beginning and end of farrowing respectively (describing an increase of 50% of the respective average levels found in this study).

Hierarchical mixed models were used for continuous outcomes (CI and ADG at 3-4 weeks of age) for analysis of piglet level dataset (outcome variables measured at piglet level) at first four

198 levels. Piglet within sow, sow within trial batch, trial batch within farm and farm were included as
199 random factors. Similarly to the sow level models, final models were built after initial univariate
200 analysis. The full model for CI included farrowing duration, piglet BW_B, number of born piglets,
201 colostrum Hp, colostrum protein (%) and colostrum IgG as continuous, and sow feed and piglet
202 birth order as categorical explanatory variables. The full model for piglets ADG at 3-4 weeks of age
203 included piglet BWB, piglet age at weighing (days), CI (g) categories (≤ 200, 201-250, 251-350, ≥
204 351) farrowing duration, number of live-born piglets, colostrum SAA and colostrum fat (%) as
205 continuous, and piglet birth order as categorical explanatory variables. The CI categories were made
206 following the categories mentioned in (Quesnel at al. 2012).

207 Similar four level mixed logit models were used for piglet level dichotomous outcome
208 variables (death before weaning, diarrhea at 7 days of age – yes/no and diarrhea at weaning –
209 yes/no). The full model for death before weaning included piglet BW_B, CI, number of born piglets
210 and back fat at farrowing as continuous explanatory variables. The full model for diarrhea at 7 days
211 of age included number of stillbirth piglets, plasma Hp, colostrum IgA and back fat at farrowing as
212 continuous, and litter diarrhea at 24 h post-partum (yes/no) and progesterone at farrowing (≤6 and
213 >6 ng/ml) as categorical explanatory variables. The full model for diarrhea at weaning included
214 back fat at weaning, colostrum IgM and piglet BW_B as continuous explanatory variables. All the
215 same model-building strategies were used as in the sow level mixed linear and logistic models.

216 We performed the statistical analysis with the Stata 14.0 (StataCorp, TX) and SPSS 24.0
217 software (IBM, Chicago, IL; USA) considering a *P*-value ≤ 0.05 as being statistically significant.

218 # 3. Results

219 ## *3.1 Descriptive results*

220 In total, 229 sows with 3,210 live-born piglets were included in the study. Sows had an
221 average parity of 3.5 ± 0.1 (mean ± SEM; range 1 to 8) and an average gestation length of 115.2 ±

0.07 (112 to 119) days. On average farrowing lasted 265.1 ± 9.8 min. Number of stillborn piglets was 1.1 ± 0.1. Litter size averaged 15.0 ± 0.2 live-born piglets, with average birth weight of 1338.2 ± 5.8 g, weaning weight 7229.9 ± 45.3 g, and ADG from birth to weaning 236.1 ± 1.8 g. At the herd level, descriptive data for the outcome and predictor variables are summarized in Table 2.

3.2 Sow back fat, blood parameters and physiology

Average sow back fat was 20.6 ± 0.3 mm (10.0 to 36.0 mm) and 16.7 ± 0.3 mm (6.0 to 30.0 mm) at farrowing and weaning respectively. Plasma Hp and SAA were 1882.8 ± 42.4 mg/l and 19.6 ± 2.2 mg/l respectively.

3.3 Sow farrowing characteristics, colostrum yield and colostrum composition

Average CY per sow was 4,346.1 ± 84.8 g (766 to 9,239 g). Average sow colostrum IgG, IgA and IgM were 80.0 ± 1.9, 10.3 ± 0.2 and 4.9 ± 0.1 mg/ml respectively. Average sow colostrum protein, fat and lactose percentage were 16.6 ± 0.1, 4.5 ± 0.1 and 4.5 ± 0.1, respectively. The result of multivariate linear mixed regression analyses with sow colostrum and farrowing characteristics are summarized in Table 3. The regression analysis revealed that the factors associated with CY were: plasma Hp, farrowing duration and live-born piglets. An additional individual live-born piglet increased the CY by 93.6 g ($P < 0.01$). On the other hand, an additional minute of farrowing duration lower the CY by 2.2 g ($P = 0.01$). However, sow plasma Hp level positively correlated with sow CY ($P < 0.05$). Sow colostrum Ig content (which included IgG, IgA and IgM) was significantly influenced by sow parity, with older sows having a higher immunoglobulin content, except for IgM (which was lower in parities over 5). In addition, sow back fat at farrowing was positively correlated with colostrum IgA level ($P < 0.01$). Moreover, older sows (parity over 5) had a significantly larger litter size (live-born) and longer farrowing duration than the younger sows.

The average progesterone level in each herd is described in Figure 1. Sow average plasma progesterone level at start of farrowing was 3.8 ± 0.2 ng/ml and at the end 3.2 ± 0.2 ng/ml. Fifteen

246 percent of the sows had 50% higher plasma progesterone than the average level at the beginning of
247 farrowing. Moreover, at the end of the farrowing some of the sows (n = 24) still had 50% higher
248 than the average progesterone level in plasma at that stage. However, we did not establish
249 significant relationship between CY with progesterone level around farrowing in the multivariable
250 regression analysis, including herd as a random factor.

251 ### *3.5 Piglet colostrum intake in relation to growth and mortality*

252 Piglet average CI was 308.9 ± 2.7 g (0 to 955 g). Thirty six percent of the piglets received
253 less than 250 g of colostrum and 23% percent of piglets received less than 200 g of colostrum.
254 Piglet CI was associated with body weight of piglet at birth, live-born litter size and colostrum
255 protein concentration (Table 4). The CI increased by 0.19 g ($P < 0.001$) for 1 g of BW_B. On the
256 other hand, CI was negatively associated with number of live-born piglets, decreasing by 9.4 g for
257 each additional live-born piglet ($P < 0.001$). Similarly, for an increase of one percentage unit of
258 colostrum protein, piglet CI decreased by 5.7 g ($P < 0.001$). Both piglet CI and birth weight were
259 positively associated with piglet ADG (birth to weaning), a CI of 1 g was associated with an
260 increase in ADG of 0.13 g until weaning ($P < 0.001$). However, for piglets dying or surviving until
261 weaning, colostrum intake averaged 203.6 ± 11.6 g and 339.5 ± 3.5 g respectively ($P < 0.001$;
262 Figure 2). Weaning weights and growth (ADG) of the piglets were related to CI independently of
263 BW_B ($P = 0.001$). If a piglet consumed ≤ 200 g of colostrum and managed to survive, its growth
264 was on average the lowest, while proportionally higher CI correlated with higher weaning weight
265 (Figure 3).

266 ### *3.6 Sow back fat and piglet colostrum intake with relation to diarrhea and antibiotic*
267 ### *treatment*

268 All the models regarding piglet mortality, diarrhea and antibiotic use are presented in Table
269 5. We found that the lower the sow back fat thickness at farrowing the higher was the risk for
270 piglets to die and/or for piglets to be treated with antibiotic before weaning (OR = 0.923;

271 Confidence Interval = 0.854 – 0.997; $P = 0.04$ and OR = 0.782; Confidence Interval = 0.630 –
272 0.970; $P = 0.02$ respectively). Similarly, the lower the average litter BW_B and the lower the average
273 litter CI during the first 24 h of life, the higher was the risk for piglets death before weaning (OR =
274 0.998; Confidence Interval = 0.998-0.999; $P < 0.001$ and OR = 0.994; Confidence Interval = 0.992
275 – 0.997; $P < 0.001$ respectively). On the other hand, the higher the back fat thickness at weaning,
276 the higher was the risk for piglet to have weaning diarrhea (OR= 1.18; CI = 1.02 – 1.37; $P = 0.02$).
277 The lower the IgA colostrum level, the higher was the risk of piglet to develop diarrhea during their
278 first week of life (OR = 0.771; CI = 0.598 – 0.993; $P = 0.04$), while the lower the level of colostrum
279 SAA the higher was the risk of piglet litter diarrhea during the first day of their life (OR = 0.998; CI
280 = 0.995 – 1.0; $P = 0.05$). However, piglets born from sows having more than 50% higher level of
281 sow plasma progesterone at the end of farrowing (> 4.9 ng/ml), the higher was the risk of litter
282 diarrhea during the first day of their life (OR = 3.71; CI = 1.04 – 13.23; $P = 0.04$).

283 ## 4. Discussion

284 A prolonged duration of farrowing and low Hp in sow plasma decreased sow CY.
285 Moreover, sow parity had effects on colostrum Ig content and older sows (parity over 5) had more
286 IgG and IgA in their colostrum than younger sows. Sows with thicker back fat at farrowing had
287 higher colostrum IgA. In addition, piglet CI was correlated with ADG and survivability until
288 weaning. We also found that piglet antibiotic treatment and survival until weaning were negatively
289 associated with back fat thickness of the sow at farrowing. Earlier studies (Devillers et al. 2011;
290 Decaluwé et al. 2014) reported that sow CY and piglet CI were positively associated with
291 survivability and weight gain during the first 6 weeks of life, stressing the importance of colostrum
292 availability and intake for piglets. We noted in our study that 36% of the piglets got less than 250 g
293 of colostrum, and 23% percent of piglets got less than 200 g of colostrum. We established (Fig. 2)
294 that insufficient CI could lead to a significant increase in piglet mortality until weaning (Decaluwé
295 et al. 2014). It was also described by Devillers et al. (2011) that mortality rate can be as low as 7.1%

296 when piglets ingest more than 200 g and can be increased up to 43.4% when intake is less than 200
297 g. Weaning weights of the piglets were found to be dependent on CI(Decaluwé et al. 2014). Our
298 findings support the suggestion that a minimum average amount of 250 g colostrum intake is
299 recommended to achieve good growth and body weight before weaning (Quesnel et al. 2012), as it
300 is showed in figure 3.

301 Sow CY in this study was comparatively higher than in studies done previously, calculated
302 using the same method (Quesnel, 2011; Decaluwé et al. 2013; Decaluwé et al. 2014; Declerck et al.
303 2015). Sow CY is highly variable and this variation can be attributed to sows, piglets,
304 environmental traits and herd management (Quesnel, 2011; Declerck et al. 2015; Declerck et al.
305 2017; Devillers et al. 2007). In the present study, the variability of CY among different parity
306 groups was not significant, supporting previous findings (Quesnel, 2011; Declerck et al. 2015). This
307 is in contrast with Devillers et al. (2007) who reported that second and third parity sows produces
308 more colostrum than primiparous and older sows. Also Decaluwé et al. (2013) found that sows of
309 parities one and three produced more colostrum than other parity sows.

310 In our study, CY was significantly associated with litter size. This observation is not in
311 accordance with previous studies (Quesnel, 2011; Devillers et al. 2007), possibly because in recent
312 years litter size has been constantly increasing and those reference studies are now old and were
313 based on smaller litter size than are currently the case. Sow farrowing duration was relatively longer
314 than in earlier studies (Declerck et al. 2015; Devillers et al. 2007). This was probably due to the
315 larger litter size in our studies, as it has been found that farrowing duration is significantly
316 influenced by the litter size and number of stillborn piglets (Oliviero et al. 2010; Björkman et al.
317 2017). Interestingly, we established that CY was negatively associated with farrowing duration,
318 although previous studies did not report this correlation (Devillers et al. 2007; Foisnet et al. 2010;
319 Declerck et al. 2015). This could be explained by hormonal changes, because the durations of
320 farrowing and colostrum production are mainly regulated by hormones and therefore sow

physiological condition could be influential (Algers and Uvnäs-Moberg, 2007). Several hormones regulate the both onset and the progress of farrowing and colostrum production, namely progesterone, prolactin and oxytocin. During longer farrowing duration, opioids (due to a pre-existing stress condition) might inhibit oxytocin and prolactin secretion (Jarvis et al. 1997), and thereby also reducing the CY. However, progesterone, which remains at a high concentration throughout the entire pregnancy, should decrease markedly with the approach of parturition while prolactin increases (Algers and Uvnäs-Moberg, 2007). In the case that sows at farrowing experience a delayed decrease in progesterone concentrations, and thereby a delayed increase in prolactin, this might explain the lower levels of colostrum (Foisnet et al. 2010; Quesnel et al. 2012).

A decrease in plasma progesterone and a rise in plasma concentration of prolactin prior to farrowing are known to initiate nest building behavior in prepartum sows (Algers and Uvnäs-Moberg, 2007). Yun et al. (2014) demonstrated that onset of nest building, by providing abundant nesting materials and space, was accompanied by an increased in plasma oxytocin concentration in prepartum sows. Moreover, the study of Yun et al. (2014) confirmed that for sows in a non-crated system a plentiful supply of nesting materials prior to parturition tended to increase piglet serum IgG and IgM concentrations during early lactation. Although it was not the primary purpose of this study to investigate housing condition at farrowing, it is very interesting that the average progesterone levels were numerically lowest in the herds where sows had unlimited access to nest building materials and sows were loosely housed in pens (herd 6). Meanwhile, the average progesterone level was higher in those herds in crate housing and in which sows had limited access to or no nesting material (Fig. 1). This is in line with Yun et al. (2014) and Farmer (2016), suggesting that nesting materials and space for the movement of the sow may be beneficial for improving colostrum production, successful CI by piglets and ensure better quality colostrum. The fact we could not establish an association between progesterone level and CY, could be due to the average progesterone level at farrowing being higher in this study than previously reported (Foisnet

et al. 2010). In the present study, the higher plasma progesterone at the end of farrowing also increased the risk of neonatal piglet diarrhea at first day of life. This is probably because at each single herd level the higher than average progesterone level and lower use of nesting material were associated with a detrimental effect on sow colostrum quality as published previously (Foisnet et al. 2010; Yun et al. 2014). Piglets are born without immunity and colostrum provides the immunological protection Rooke and Bland, 2002). Therefore, we can assume that litters of sows with higher plasma progesterone suffered from neonatal diarrhea because of lower immunoglobulin intake. This is supported by our findings that higher colostrum IgA content reduces the incidence of piglet diarrhea during the first week of their life. Beyond the neonatal period, the supply of maternal immunity and bioactive compounds by colostrum is relatively more important (Rooke and Bland 2002; Le Dividich et al. 2005).

At farrowing, sows undergo not only hormonal changes, but also substantial metabolic and physiological changes occur during this very short period of time (Algers and Uvnäs-Moberg, 2007) including tissue damage and inflammation response due to the parturition process (Mainau and Manteca, 2011). Therefore, we studied sow APPs as markers of acute phase response in colostrum and plasma. The acute phase response in sows can appear as nonspecific to disturbances in homeostasis due to inflammation, tissue injury during gestation and farrowing (Sorrels et al. 2007). Our current finding shows that sow plasma Hp concentrations were positively associated with CY. This association may not be directly related to the inflammation process, but it is more a reflection of Hp function as a hemoglobin binding protein (Eaton et al. 1982). Tissue damage (and hemolysis) can initially cause a decrease in serum Hp concentrations before the inflammatory stimulus initiates the Hp production in the liver. Studies with calves showed decreased Hp concentrations in the case of low-grade *Eimeria* infection (Seppä-Lassila et al. 2015) and during transportation (Arthington et al. 2003). Thus in our study, the lower plasma Hp at farrowing associated with sows having lower CY may be connected to the start of an inflammatory process, for example due to longer farrowing

causing more tissue damage, hemolysis and depletion of circulating Hp. We found that high colostrum SAA tended to be linked to reduced neonatal piglet diarrhea incidence during first day of their life. Age-dependent studies showed that SAA plasma concentration is highest in neonate piglets (Moya et al. 2007) and calves (Orro et al. 2008). Higher colostrum SAA concentrations were associated with higher serum SAA concentrations of lambs at 1-5 days of age (Peetsalu et al. 2019). The function of SAA abundance in colostrum was suggested by Larson et al. (2003) to have a local beneficial effect on the neonatal gut. They found that colostrum-associated SAA peptide enhanced innate protection by stimulating intestinal epithelial cells and mucous production, thereby preventing binding of enteropathogenic bacteria. This could explain our findings between high SAA in colostrum and reduced piglet diarrhea. Interestingly, in a recent study we found that supplementing sow diet with resin acid-enriched composition (RAC) tended to increase the sow colostrum SAA (Hasan et al. 2018). On the basis of the results of the present study, higher SAA content in colostrum could be seen as a positive feature for improving piglet survival. Sow body condition at farrowing has significant influence on CY. Decaluwé et al. (2013) reported that the sow back fat changes at the end of gestation were negatively associated with sow CY. Our studies revealed that sow back fat thickness at farrowing is positive correlated with colostrum IgA, underlining the importance of fit sows at the start of lactation, avoiding excessive leanness. Studies also revealed a significant correlation between sow back fat during lactation and piglet survival and growth (Grandinson et al. 2005). Our present findings, on back fat thickness and colostrum IgA content confirms previous studies where high enough level of sow body reserves are considered important at the start of lactation for the piglets growth and survivability (Grandinson et al. 2005).

5. Conclusion

In conclusion we found that extended farrowing can be detrimental for colostrum yield. Easing the farrowing process, by allowing more space and providing nesting materials, could therefore be benefit for piglet survival and growth. In this study we confirmed also that CI was

396 positively correlated with survivability and ADG of piglets until weaning. Sows with higher back
397 fat at farrowing had higher levels of IgA in colostrum, and piglets from such sows were at less risk
398 to die and to be treated with antibiotic until weaning. Moreover, we found that SAA and IgA in
399 colostrum had beneficial influence on reducing piglet diarrhea.

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495 Figure captions

496 Figure 1. Mean and SEM plasma progesterone in five herds at the beginning of farrowing.

497 *** Abundant of nesting materials in farrowing pen (entire pen floor with 15-20 cm of straw)

498 ** Limited amount of nesting material in farrowing crate (2-4 liters of saw dust and/or straw)

499 * No nesting material in farrowing crate

500 Figure 2. Piglet colostrum intake and survivability until weaning .Mean ± SEM

501 Figure 3. Correlation between ADG and different colostrum intake categories, with respective

502 indicative average weight at 3-4 weeks found in this study piglets population. Mean ± SEM

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517 Table 1. Specific information for individual herd. Mean ± SEM

	Herd number					
	1	2	3	4	5	6
Country	FI	FI	FI	FI	NL	FI
Sow breed	Topigs TN70	Topigs TN70	DanAvl	DanAvl	Topigs 20	DU × NL
Number of sows	44	47	39	20	60	20
Number of batches	4	8	9	5	2	3
Sow parity	3.8 ± 0.2	3.6 ± 0.3	3.3 ± 0.3	3.5 ± 0.4	3.1 ± 0.1	3.6 ± 0.4
1 to 2	9	16	18	7	21	7
3-5	27	23	14	9	35	9
Over 5	8	8	7	4	4	4
Housing at farrowing	Crate	Crate	Crate	Crate	Crate and pen	pen
Feeding	Standard lactation	Standard lactation	Standard lactation	Standard lactation	Standard lactation	Standard lactation
Nesting material	No	Some*	Some*	No	Some*	Plenty**

518 FI= Finland; NL = Netherland; DU × NL = Duroc × Norwegian Landrace

519 * 2-4 liters (saw dust and/or straw)

520 ** The whole pen floor with 15-20 cm of straw

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533 Table 2. Descriptive result of individual herd. Data presented in mean ± SEM.

	Herd number					
	1	2	3	4	5	6
Farrowing and sow characteristics						
Gestation length, days	115	115.6	116.2 ± 0.1	115	114.4 ± 0.1	115.2 ± 0.2
Farrowing duration, min	211.9 ± 10.7	200.6 ± 12.9	329.2 ± 24.2	261.7 ± 22.1	306.7 ± 27.4	287.8 ± 23.9
Litter size	16.1 ± 0.5	16.7 ± 0.6	14.6 ± 0.6	17.1 ± 0.6	16.5 ± 0.5	16.1 ± 0.5
Live-born piglets	15.3 ± 0.5	15.5 ± 0.5	13.1 ± 0.5	16.5 ± 0.6	14.9 ± 0.4	15.4 ± 0.5
Stillborn piglets	0.8 ± 0.1	1.1 ± 0.2	1.4 ± 0.2	0.6 ± 0.2	2.7 ± 0.5	0.6 ± 0.2
Birth interval, min	14.4 ± 0.9	13.7 ± 0.8	26.4 ± 2.7	16.6 ±	18.6 ± 1.2	-
Birth time, min	112.1 ± 3.1	100.3 ± 2.9	180.8 ± 7.9	142.2 ± 6.7	147.5 ± 4.1	-
Litter characteristics						
Piglet BW_B (live born), g	1445.7 ± 14.1	1275.0 ± 12.4	1413.6 ± 14.5	1220.48 ± 16.5	1279.2 ± 10.4	1446.1 ± 21.7
Piglet weight (weaning: ear tagged), g	6918.8 ± 105.8	6757.4 ± 106.3	7718.4 ± 161.2	5392.0 ± 149.2	7939.5 ± 55.28	6061.0 ± 135.5
ADG (ear tagged), g	257.8 ± 4.3	246.1 ± 4.6	212.9 ± 5.0	224.0 ± 7.5	228.2 ± 1.7	246.3 ± 7.1
Piglet age (weaning) days	21.0	21.6 ± 0.02	29.6 ± 0.09	18.1 ± 0.09	28.9 ± 0.03	19.4 ± 0.2
CY, g	4658.5 ± 221.5	4009.4 ± 145.9	4132.2 ± 223.1	4336. 1 ± 268.4	4710.6 ± 129.4	3846.5 ± 367.3
CI, g	332.0 ± 6.6	274. 3 ± 5.8	343.5 ± 7.2	270.9 ± 8.1	331.1 ± 4.5	262.5 ± 10.0
Sow physiology						
BF_F	21.8 ± 0.4	22.1 ± 0.8		17.1 ± 0.6	19.4 ± 0.3	
BF_W	10.3 ± 0.3	17.5 ± 0.9		14.3 ± 0.5	15.2 ± 0.3	
Progesterone (farrow start), ng/ml	5.7 ± 0.5	3.4 ± 0.2	2.4 ± 0.1	4.1 ± 0.6	-	1.6 ± 0.2
Progesterone (farrow end), ng/ml	4.6 ± 0.7	3.0 ± 0.2	1.7 ± 0.2	3.8 ± 0.9	-	1.8 ± 0.3
Plasma SAA, mg/l	20.6 ± 5.5	14.9 ± 1.6	29.35 ± 6.1	16.6 ± 2.1	-	12.59 ± 3.9
Plasma Hp, mg/l	1762.9 ± 83.0	1895.3 ± 66.5	2100 ±113.7	1824.7 ± 71.4	-	1815.3 ± 182.9
Colostrum characteristics						
Fat, %	4.2 ± 0.2	4.6 ± 0.2	4.6 ± 0.1	4.2 ± 0.2	4.6 ± 0.1	-
Protein, %	16.8 ± 0.4	17.0 ± 0.3	16.9 ± 0.3	16.3 ± 0.7	16.0 ± 0.3	-
Lactose, %	4.3 ± 0.05	4.1 ± 0.05	5.5 ± 0.06	4.3 ± 0.04	4.3 ± 0.04	-
DM, %	27.2 ± 0.5	27.7 ± 0.4	28.5 ± 0.4	27.3 ± 0.6	26.7 ± 0.3	-
IgG, mg/ml	79.4 ± 3.9	71.5 ± 2.7	63.8 ± 2.2	74.4 ± 3.8	105.8 ± 3.6	54.8 ± 4.8
IgA, mg/ml	9.7 ± 0.4	11.71 ± 0.5	9.4 ± 0.4	9.59 ± 0.71	-	11.5 ± 1.37
IgM, mg/ml	4.2 ± 0.2	4.8 ± 0.2	4.6 ± 0.2	7.0 ± 0.4	-	4.5 ± 0.4
Colostrum SAA, mg/l	330.1 ± 37.6	369.9 ± 37.9	283.2 ± 27.4	284.1 ± 30.5	537.6 ± 31.1	-
Colostrum Hp, mg/l	1242.2 ± 65.4	1340.0 ± 63.8	1356.2 ± 60.6	1505.3 ± 90.4	1292.4 ± 45.6	-

534 BW_B = Body weight at birth; ADG = Average daily gain; CY = Colostrum yield; CI = Colostrum

535 intake; BF_F = Back fat at farrowing; BF_W = Back fat weaning; SAA = Serum amyloid A; Hp =

536 Haptoglobin

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538 Table 3. Parameter estimates of the multivariable linear mixed model with sow colostrum yield,

539 litter size, colostrum IgG, IgA, IgM and farrowing duration as the outcome variable.

Outcome variables	Predictor variables	Coefficient	SE	*P*-value	Wald test *P*-value
CY, g	Plasma Hp	0.427	0.196	0.029	
	Farrowing duration	-2.26	0.911	0.013	
	Live-born piglets	93.609	27.064	0.001	
	Constant	2479.714	592.769	<0.001	
Litter size (Total born)	Parity category				0.109
	1-2	0			
	3-5	0.751	0.576	0.192	
	Over 5	1.296	0.623	0.037	
	Constant	15.863	0.57	<0.001	
Colostrum IgG	Parity category				0.002
	1-2				
	3-5	0.089	0.041	0.030	
	Over 5	0.154	0.045	0.001	
	Constant	4.409	0.095	<0.001	
Colostrum IgA	Parity category				0.024
	1-2	0			
	3-5	0.186	0.119	0.116	
	Over 5	0.333	0.122	0.006	
	Back fat farrowing	0.02	0.007	0.009	
	Constant	2.699	0.159	<0.001	
Colostrum IgM	Parity category				0.026
	1-2	0			
	3-5	0.008	0.077	0.921	
	over 5	-0.177	0.08	0.027	
	Plasma Hp	0.0001	0.00006	0.038	
	Plasma SAA	-0.003	0.001	0.026	
	Constant	2.025	0.146	<0.001	
Farrowing duration	Parity category				0.031
	1-2	0			
	3-5	-0.030	0.068	0.659	
	over 5	0.151	0.074	0.042	
	Litter size (total born)	0.035	0.008	<0.001	
	Constant	4.734	0.150	<0.001	

540 SE = Standard error; CY = colostrum yield; Hp = Haptoglobin; SAA = Serum amyloid A

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544 Table 4. Parameter estimates of the multivariable linear mixed model with piglet colostrum intake

545 (g) and average daily gain (g) as the outcome variable.

Outcome variables	Predictor variables	Coefficient	SE	*P*-value
CI, g	BW_B	0.198	0.008	<0.001
	Live born piglets	-9.479	1.366	<0.001
	Colostrum proteins	-5.713	1.859	0.002
	Constant	310.361	39.200	<0.001
ADG, g	Weaning age	-2.322	1.124	0.039
	Birth time, min	-0.033	0.013	0.012
	BW_B	0.077	0.005	<0.001
	CI, g			
	≤ 200	0		
	201-250	21.417	4.929	<0.001
	251-350	28.97	4.136	<0.001
	≥ 351	40.94	4.379	<0.001
	Live born piglets	2.944	0.872	0.001
	Colostrum fat (%)	-4.439	1.869	0.018
	Constant	113.449	33.532	0.001

546 SE = Standard error; CI = colostrum intake; AD =average daily gain; BW_B = Body weight at birth

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557 Table 5. Parameter estimates of the logit model with piglet litter diarrhea 24 h, diarrhea at one week
558 of age death before weaning, diarrhea at weaning as the outcome variable.

Outcome variables	Predictor variables	OR	95% Confidence Interval	*P*-value
Death before weaning	Back fat (farrowing)	0.923	0.854 - 0.997	0.042
	BW_B	0.998	0.998 - 0.999	<0.001
	CI, g			<0.001
	≤ 200	1		
	201-250	0.272	0.116 - 0.637	
	251-350	0.205	0.101 - 0.417	
	≥ 351	0.147	0.067 - 0.324	
Diarrhea at weaning	Back fat (weaning)	1.18336	1.021 - 1.372	0.025
Diarrhea at one week	Colostrum IgA	0.771	0.598 - 0.993	0.044
Litter diarrhea 24 h	Progesterone (farrowing end), ≤ 4.9 ng/ml	1		
	> 4.9 ng/ml	0.938	0.999 – 2.422	0.050
	Colostrum SAA	0.998	0.995 - 1.000	0.046
Litter antibiotic treatment	Back fat (farrowing)	0.782	0.630-0.970	0.025

559 OD = Odd ratio; CI = colostrum intake; BW_B = Body weight at birth

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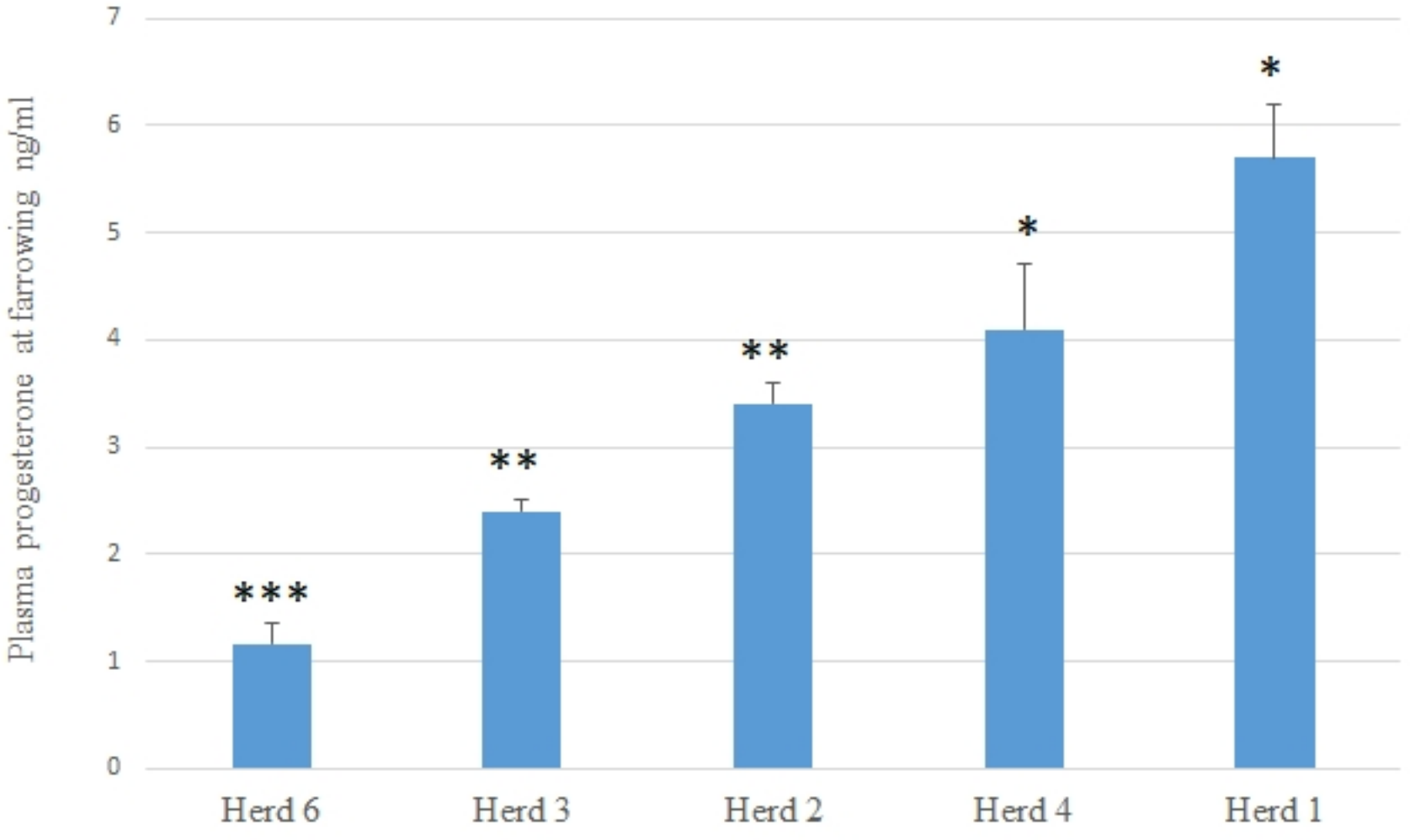
Plasma progesterone at farrowing ng/ml
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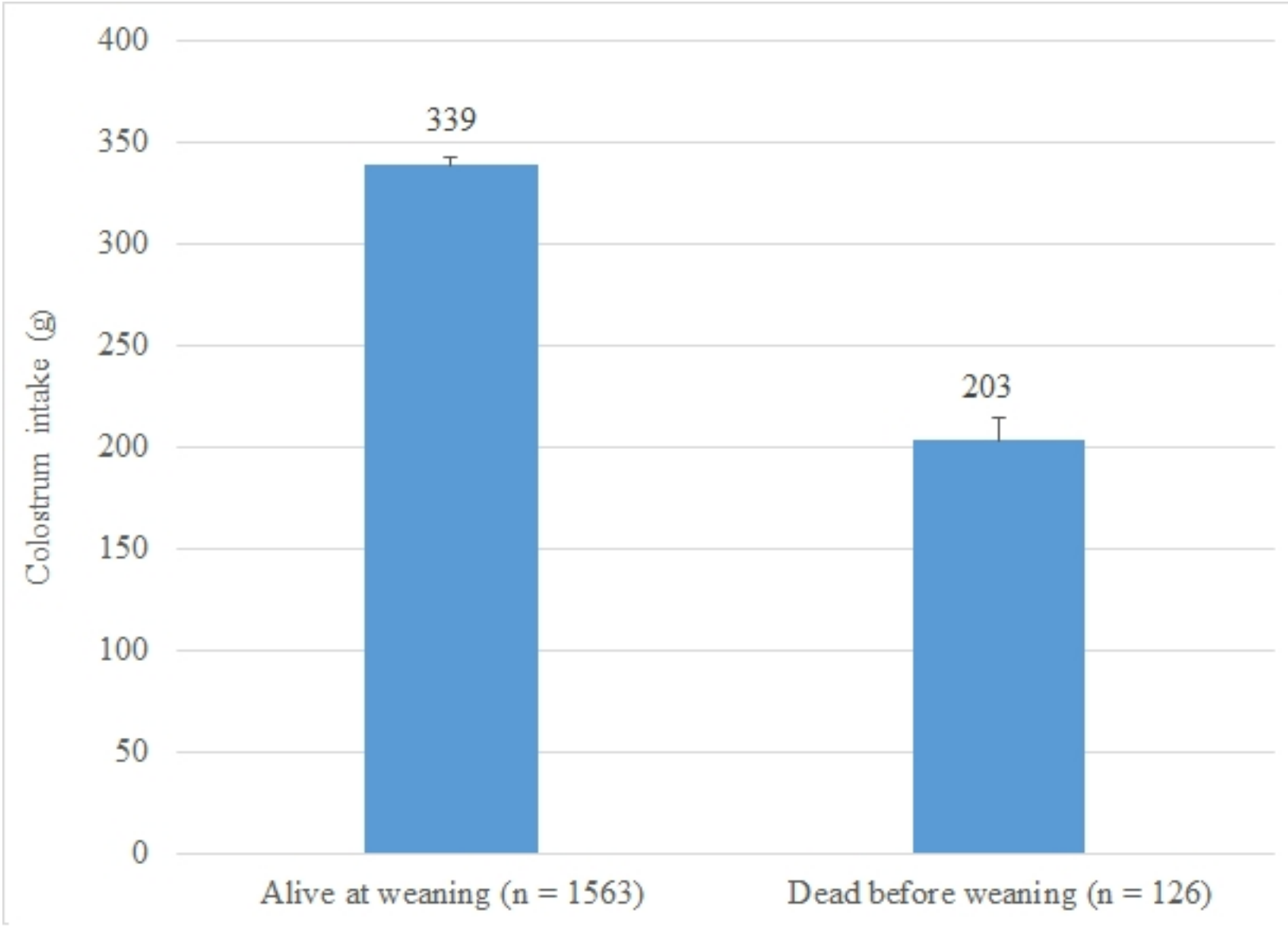
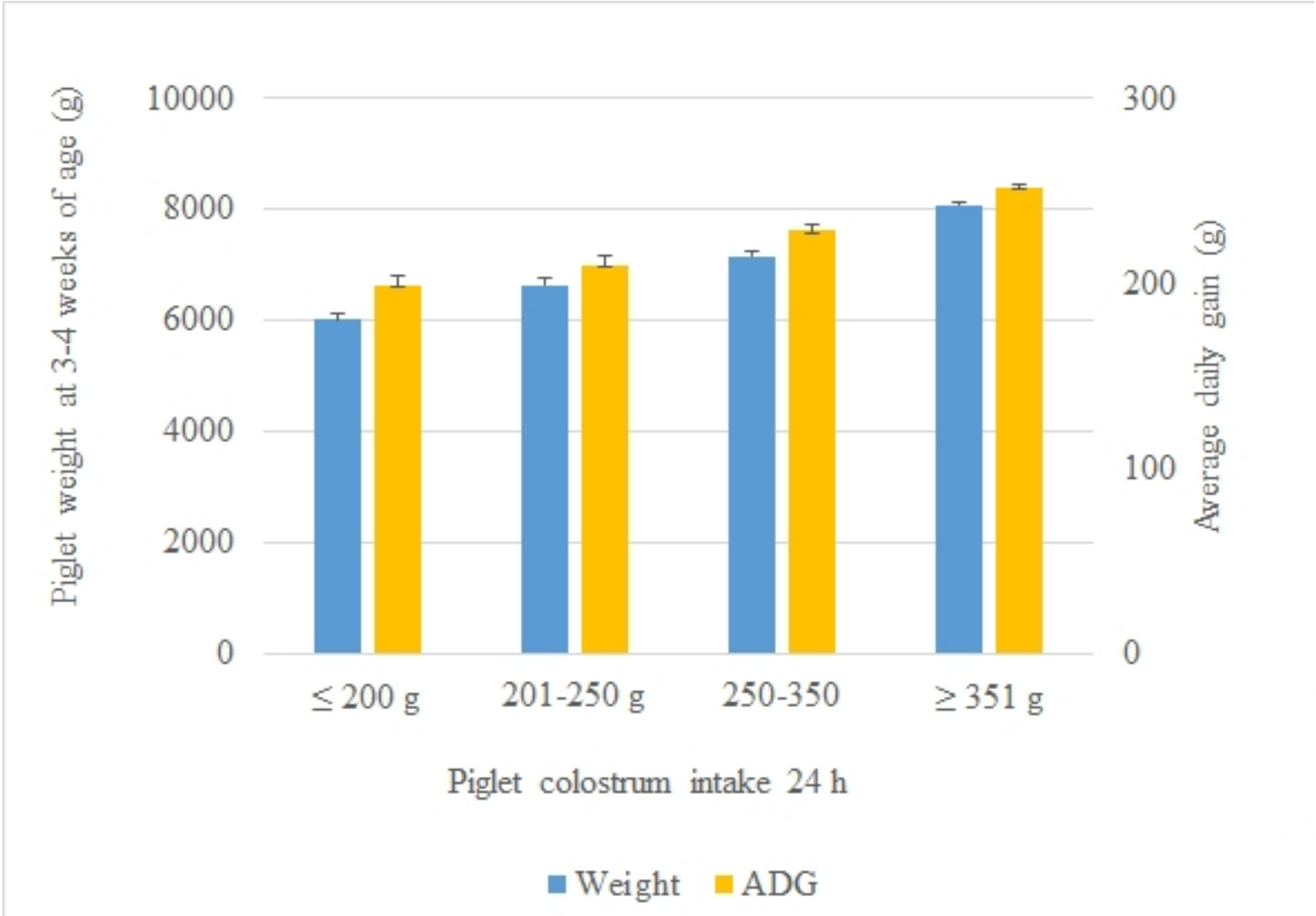
Herd 2
Herd 4
Herd 1


400
350
300
250
200
150
100
50
0
Colostrum intake (g)
339
203
Alive at weaning (n = 1563)
Dead before weaning (n = 126)


Piglet weight at 3-4 weeks of age (g)
10000
8000
6000
4000
2000
0
300
200
100
0
Average daily gain (g)
≤ 200 g
201-250 g
250-350
≥ 351 g
Piglet colostrum intake 24 h
Weight
ADG

Conflict of Interest

All authors declare they have no conflicts of interest whatsoever